
**State of California
The Resources Agency
Department of Water Resources**

**INTERIM REPORT
SP-F10, TASK 3B**

**Oroville Facilities Relicensing
FERC Project No. 2100**



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**INTERIM REPORT
SP-F10, TASK 3B
STEELHEAD REARING TEMPERATURES**

**Oroville Facilities Relicensing
FERC Project No. 2100**

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1.0 SUMMARY

The objective of this literature review and evaluation is to identify temperature ranges that are suitable for steelhead fry and juvenile rearing, and to provide a basis from which Resource Actions could be developed to improve habitat conditions in the lower Feather River. A review was conducted of available literature to fulfill the requirements of Task 3B of SP-F10. Reported suitable rearing temperatures for steelhead fry and juveniles in laboratory and field settings were sought out. A brief description of the types of studies from which suitable steelhead rearing water temperature ranges were derived, as well as the effects of exposure to water temperatures outside the reportedly suitable water temperature range, were presented. Average water temperatures in the reach of the Feather River where juvenile steelhead are reported to rear were compared to reported suitable water temperature ranges. The analysis revealed that in the Low Flow Channel (LFC) of the Feather River, water temperatures are suitable for steelhead fry and juvenile rearing during all months of the year.

2.0 PURPOSE

The purpose of this portion of Task 3B of SP-F10 is to conduct a literature review to summarize the reported suitable rearing water temperatures for juvenile steelhead and the effects of increased water temperatures on their physiology and behavior.

On March 19, 1998, naturally spawned Central Valley steelhead (*Oncorhynchus mykiss*) were listed as threatened under the federal Endangered Species Act (ESA) by the US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NOAA Fisheries) (NOAA 1998). The Central Valley Evolutionarily Significant Unit (ESU) includes all naturally spawned populations of steelhead (and their progeny) in the Sacramento and San Joaquin rivers and their tributaries, which includes the naturally spawned steelhead in the Feather River (NOAA 1998). In order to evaluate potential relationships between project operations and ESA-listed steelhead, it is desirable to collect data regarding steelhead rearing locations and the effects of Feather River water temperatures on rearing juvenile steelhead. This portion of Task 3B of SP-F10 is a literature review designed to elucidate suitable water temperatures for rearing steelhead and the potential effects of water temperatures outside the reported suitable water temperature range.

In addition to the ESA, Section 4.51(f)(3) of 18 CFR requires reporting of certain types of information in the Federal Energy Regulatory Commission (FERC) application for license of major hydropower projects, including a discussion of the fish, wildlife, and botanical resources in the vicinity of the project (Code of Federal Regulations 2001). The discussion is required to identify the potential impacts of the project on these resources, including a description of any anticipated continuing impact from on-going and future operations. As a subtask of Study Plan (SP) F-10, *Evaluation of Project Effects on Salmonids and their Habitat in the Feather River Below the Fish Barrier Dam*, Task 3B fulfills a portion of the FERC application requirements by providing a literature review that summarizes suitable water temperatures for rearing steelhead and evaluates potential effects of increased water temperatures on rearing juvenile steelhead.

Ongoing operation of the Oroville facilities affects flows, and consequently water temperatures, in the lower Feather River that may affect rearing success of salmonids. Task 3 of SP-F10 will evaluate project effects on the rearing of juvenile salmonids in the Feather River. Task 3A evaluates the relative abundance and distribution of rearing juvenile salmonids and determines the habitat characteristics of rearing salmonids in the Feather River. Task 3B consists of several components, with the overall objective of evaluating the water temperature effects on juvenile salmonid rearing, while Task 3C evaluates the project operation flow fluctuation effects on juvenile salmonid rearing. For further description of Tasks 3A, and 3C relating to juvenile salmonid rearing, see SP-F10 and associated interim and final reports.

3.0 BACKGROUND

3.1 STUDY AREA

The study area in which the results of the literature review could be applied includes the reach of the Feather River extending from the Fish Barrier Dam to the confluence with the Yuba River. This is the geographic range within the Feather River that encompasses areas in which juvenile Feather River steelhead may rear (DWR 2002a). The literature review compiled literature from a variety of laboratory and in-river studies utilizing steelhead strains from rivers located throughout a wide geographic range of North America.

3.2 FEATHER RIVER JUVENILE STEELHEAD REARING

Currently, limited information is available regarding the relative abundance and distribution of in-river rearing juvenile steelhead in the Feather River. During project construction, counts and estimates were made regarding escapement of naturally spawning steelhead in the Feather River (DWR 2001). Between 1997 and 2001, seining efforts revealed that approximately 95% of the steelhead captured in the Feather River were captured between the Fish Barrier Dam and the Thermalito Afterbay Outlet (DWR 2002b). Neither data set indicates specific rearing locations or relative abundance of juvenile steelhead. Snorkel surveys conducted from March through August in 1999, 2000, and 2001 indicate that the majority of young-of-year (less than 100mm FL) steelhead observations occurred in the upper mile of the reach extending from the Fish Barrier Dam to the Thermalito Afterbay Outlet. In each of the 3 years surveyed, less than 1% of the observed young-of-year (YOY) steelhead were observed downstream of the Thermalito Afterbay Outlet (DWR 2002b). In 2002, DWR conducted preliminary mark-recapture experiments to evaluate site fidelity of juvenile steelhead in the Low Flow Channel (LFC) of the Feather River. It was observed that most juvenile steelhead recaptured in the LFC during the experiment exhibited high site fidelity (DWR 2003), although relatively few juvenile steelhead were recaptured. In general, there are several reasons that relatively little information regarding steelhead rearing in the Central Valley, including the Feather River, is available.

For most rivers and streams of the Sacramento River Basin, detailed information on steelhead rearing sites and abundance is limited because steelhead life-history traits have hampered steelhead monitoring and research (McEwan 2001). Adults tend to migrate during high flow periods, making them difficult to observe (McEwan 2001). Maintaining counting weirs and other monitoring equipment and structures during these higher flow periods can be challenging (McEwan 2001). Steelhead redds are difficult to observe because steelhead spawn at higher flows than do Chinook salmon (McEwan 2001). Steelhead redds are difficult to detect in the Feather River due to superimposition resulting from heavy utilization of spawning riffles by both Chinook salmon and steelhead, and because water clarity is generally poor during the winter months when steelhead spawning occurs (DWR et al. 2000).

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It has been reported that, in general, newly emerged steelhead fry initially rear in relatively slow moving edgewater. As the fry grow larger, they move into the faster moving water of riffles and runs. Larger juveniles may inhabit deeper runs and pools (Barnhart 1986; Moyle 2002a). Based on the limited swimming ability of most salmonid fry, it is inferred that that initial rearing occurs in proximity to spawning areas. As indicated by Barnhart (1986) and Moyle (2002b), as growth occurs, migration to areas with higher food abundance and lower predation risk, such as riffles, occurs. Data on steelhead distribution within the Feather River indicates that steelhead rearing occurs within the reach extending from the Fish Barrier Dam to the Thermalito Afterbay Outlet. Snorkeling surveys performed by DWR from March through August in 1999, 2000, and 2001 indicate that 91%, 77%, and 84% of all the young-of-year (less than 100mm FL) steelhead observations occurred in the upper mile of the reach extending from the Fish Barrier Dam to the Thermalito Afterbay Outlet. In each of the 3 years surveyed, less than 1% of the observed YOY steelhead were observed downstream of the Thermalito Afterbay Outlet (DWR 2002b). Additionally, some steelhead have been observed spawning in the small secondary channels of the reach of the Feather River extending from the Fish Barrier Dam to the Thermalito Afterbay Outlet, where substrate size is smaller and cover is greater than in the main river, thereby providing a suitable area for spawning and juvenile rearing (DWR 2001).

Average monthly water temperatures in the reach of the Feather River from the Fish Barrier Dam to the Thermalito Afterbay Outlet range from 47°F (8.3°C) in winter to 65°F (18.3°C) in the summer. Water temperatures downstream of the Thermalito Afterbay Outlet are generally warmer, with the maximum mean daily water temperature at the Thermalito Afterbay Outlet reaching approximately 70°F (21.1°C) in the summer (DWR 2001). Because daily summer water temperatures often exceed 70°F below the Thermalito Afterbay Outlet, it is unlikely that steelhead would rear in High Flow Channel if suitable rearing habitat was available with cooler water temperatures. Thus, current knowledge regarding juvenile steelhead rearing locations suggests that most steelhead rearing appears to be concentrated between the Fish Barrier Dam and the Thermalito Afterbay Outlet, and specifically in the upper section of this reach. Snorkel surveys have confirmed that the area below the Thermalito Afterbay outlet harbors little to no rearing steelhead (DWR et al. 2000).

Laboratory studies on Feather River hatchery and naturally spawned steelhead suggest that rearing juveniles prefer temperatures between 62 and 68°F (16.7 and 20°C) (Myrick 1998; Myrick et al. 1999). Furthermore, naturally spawned Feather River steelhead have been observed to rear successfully at water temperatures near 65°F (18.3°C) (DWR et al. 2000). Young-of-year Feather River steelhead have been observed rearing in habitats where average daily water temperatures were 63°F (17.2°C), and where daily maximal water temperature exceeded 66°F (18.9°C) (DWR et al. 2000).

In order to provide additional information regarding the distribution and relative abundance of rearing juvenile steelhead in the Feather River, targeted surveys regarding in-channel adult steelhead rearing are being conducted for the Oroville Facilities relicensing process (DWR 2002a). Preliminary juvenile steelhead mark-

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recapture studies have begun and are scheduled to be continued and expanded in June 2003.

4.0 METHODOLOGY

4.1 LITERATURE REVIEW

A literature review to identify suitable water temperatures for rearing juvenile steelhead was conducted to supplement the mark-recapture and enclosure experiments described in Task 3B of SP-F10. Studies conducted on various strains of steelhead in various regions were included in the literature review.

Initial review of the literature revealed a relative paucity of information derived from field studies regarding suitable water temperatures for rearing juvenile steelhead in the Central Valley. However, anecdotal information derived from observations on rearing steelhead in various rivers was included in the review. In addition, several reports on steelhead in the Central Valley derive information about preferred and suitable water temperatures for rearing juvenile steelhead from a variety of literature sources that do not indicate where the studies were performed (DWR et al. 2000; McEwan et al. 1996; Rich 1987).

Information was collected from a variety of sources including journal articles, agency reports, and composite literature reviews. The literature included laboratory analyses of preferred and optimal water temperatures, as well as effects of raised water temperatures on the growth, physiology, and behavior of juvenile steelhead. For the purposes of this review, the terms suitable, preferred, and optimal are used. Suitable water temperature ranges include those that are reported for which feeding occurs without signs of abnormal behavior. Optimal water temperatures are generally reported to be those at which physiological processes occur at the highest rates (Hokanson et al. 1977; McCullough 1999). Preferred water temperature ranges are generally those that steelhead juveniles selected when given a choice within a temperature gradient or under natural conditions. For example, it has been reported that many authors define optimal water temperature as the temperature at which maximum growth occurs, while preferred water temperatures are those within the range at which any growth occurs (Sullivan et al. 2000).

Three general types of studies were sought to address the expected variability between different water temperature regimes to which wild and hatchery steelhead could be exposed. In addition, because steelhead are an unusually adaptable species (Moyle 2002a), it was expected that different strains could exhibit different water temperature preferences, optima, and tolerance ranges (suitability). Thus, literature from the Feather River, other watersheds in California, and other watersheds outside California where steelhead are native or introduced was examined.

Results from studies of Feather River steelhead are presented separately. Results from studies performed in other watersheds in California, including other Central Valley rivers, and from other watersheds outside California are presented as results from field or laboratory investigations. The effects of increased water temperatures on steelhead physiology are presented separately from the studies on thermal preference and

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thermal tolerance, regardless of the geographic area in which the studies were performed. Conclusions were drawn and recommendations were made based on the synthesis of available information.

5.0 RESULTS AND DISCUSSION

It has been reported by Bell (1991) that latitudinal differences in temperature tolerances for salmonids were approximately equal to one degree F for each degree change in latitude (Bell 1991). In order to accurately characterize whether the generalization put forth by Bell (1991) holds true for the Feather River versus other rivers and streams, studies were examined from various regions including the Feather River, other regions of California, and other regions within the range of steelhead.

5.1 FEATHER RIVER FIELD AND LABORATORY STUDIES

Available information indicates that Feather River steelhead may have a higher thermal preference and thermal tolerance than those reported for steelhead strains from regions north of the Feather River. Following is a synthesis of juvenile steelhead water temperature-related laboratory studies and field observations from the Feather River, other California rivers, and other regions.

5.1.1 Laboratory Studies of Feather River Steelhead

The optimal water temperature for juvenile rainbow trout growth has been reported to range from 59°F to 64°F (15°C to 17.8°C) (Moyle 2002b). However, laboratory studies on 300 Feather River hatchery spawned steelhead (mean SL = 54 mm) and 22 naturally spawned steelhead captured in the Feather River (mean SL = 84 mm) suggest that rearing juveniles prefer temperatures between 62°F and 68°F (16.7°F and 20°C) (Myrick 1998; Myrick et al. 1999). Experiments were performed using cyclical and constant temperature regimes. Fish were acclimated at approximately 61°F (16°C) for four days prior to the onset of experimental thermal changes. Three treatments of fish were exposed to a constant water temperature of 61 ± 0.2°F (16 ± 0.1°C) while three treatments were exposed to cyclical water temperatures designed to simulate a diel cycle. The cyclical regime was 61 ± 3.6°F (16 ± 2°C). Each of the treatment groups was fed 100%, 50%, or 25% rations calculated from the previous day's feed consumption. Thermal preferences were determined by placing fish in temperature gradient. Critical thermal maxima were determined by observing loss of equilibrium while the water temperature was raised 0.54°F (0.3°C) per minute.

Differences in water temperature preference between naturally spawned steelhead captured from the Feather River and Feather River Hatchery spawned steelhead were insignificant. In addition, thermal regime and ration level had little effect on water temperature preference of either hatchery or naturally spawned fish. However, wild steelhead that were fasted did select water temperatures that were slightly lower than fed steelhead, although the differences were not statistically significant. According to Myrick and Cech (1999), the slight difference in water temperature selection suggests that, when food is limited, juvenile steelhead select cooler water in order to reduce maintenance metabolic costs. The critical thermal maximum for hatchery spawned Feather River juvenile steelhead, determined by loss of equilibrium, was between 83°F and 85.8°F (28.4°C and 29.9°C). Wild steelhead had a significantly higher critical

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thermal maximum than their hatchery spawned counterparts, even though their temperature preferences were similar. Critical thermal maxima were not, however, affected significantly by water temperature regime, or ration (Myrick 1998; Myrick et al. 1999).

Food consumption rates differed slightly between treatments. Juvenile steelhead exposed to the cyclical water temperature regime tended to have lower food consumption rates, but the trend was not significant. In addition, fish exposed to the cyclical water temperature regime tended to be lighter than those exposed to the constant water temperature regime ($P=0.065$). Growth rates were also slightly affected by thermal regime. Although statistically insignificant, steelhead reared under the cyclic thermal regime grew slower than those fed the same ration under the constant regime (Myrick 1998; Myrick et al. 1999).

The food consumption and growth rates observed in these experiments on both thermal regimes were 1.3 to 2.7 times higher than Nimbus strain steelhead reared under similar conditions by the same authors. However, thermal preferences and critical thermal maxima were similar for the two strains (Cech et al. 1999; Myrick 1998; Myrick et al. 1999).

5.1.2 Field Observations in the Feather River

Field studies in the Feather River revealed that naturally spawned Feather River steelhead have been observed to rear successfully at water temperatures near 65°F (18.3°C) (DWR et al. 2000). Young-of-year Feather River steelhead also have been observed rearing in habitats where average daily water temperatures were 63°F (17.2°C), and where daily maximal water temperature exceeded 66°F (18.9°C) (DWR et al. 2000).

5.2 OTHER CALIFORNIA RIVERS AND STREAMS

In the Pit River, California, it has been reported that within a section of river containing a thermal plume from an inflowing cold tributary, that rainbow trout selected water temperatures of approximately 61°F to 64°F (16°C to 18°C) (Baltz et al. 1987 in Moyle 2002b). In Big Sulphur Creek, Mendocino County, California, water temperatures above 78.8°F (26°C) for extended periods in the summer caused steelhead juveniles to disappear from the creek (Kubicek and Price 1976 in Moyle 2002b).

Optimum water temperatures and preferred water temperature ranges are commonly cited in reports pertaining to California streams and rivers when it is unclear from which steelhead strains or from which regions the temperature ranges were derived. Indeed, many reports fail to define the meaning of optimal. It is assumed, in these reports, that optimum water temperatures are defined as those water temperatures at which certain physiological processes occur at maximum rates.

Examples of these incidents occur in the Biological Assessment on the Effects of the Central Valley Project and State Water Project on Steelhead and Spring-Run Chinook Salmon (DWR et al. 2000), and the Steelhead Restoration and Management Plan for California (McEwan et al. 1996). DWR et al. (2000) and McEwan et al. (1996) report that the preferred water temperature range for fry and juvenile steelhead rearing in California is between 45°F and 60°F (7.2°C and 15.6°C). In addition, McEwan and Jackson (1996) report that the preferred water temperature range is also the optimal water temperature range. Both reports cite Bovee (1978), Reiser and Bjornn (1979) and Bell (1986) as the sources for the derivation of the preferred temperature range for rearing juvenile steelhead. Bell (1986) reports that “...it can be shown that the preferential temperature for salmonid fish varies generally between 49 and 57°F.” These water temperatures equate to 9.4°C and 13.9°C. Reiser and Bjornn (1979) cite Bell’s first edition of the Fisheries Handbook of Engineering Requirements and Biological Criteria that suggest that steelhead prefer temperatures between 45.1°F and 58.3°F (7.3°C and 14.6°C) (Table 11, page 36) (Reiser et al. 1979). Bovee (1978) provides habitat suitability curves for various life stages for various salmonids including steelhead. The water temperatures at which the probability of use reaches 50% for juveniles and fry are approximately 52°F and 66°F (11.1°C and 18.9°C) and 48°F and 66°F (8.9°C and 18.9°C) respectively (Bovee 1978). None of the three reports cited by DWR et al. (2000) and McEwan et al. (1996), however, report that the experimental stocks used to determine thermal preference were from streams or rivers in California. It is unknown from which watersheds the steelhead used to determine the reported thermal preference and optima were obtained.

The report titled, Water Temperatures Which Optimize Growth and Survival of the Anadromous Fishery Resources of the Lower American River (Rich 1987), cites Bovee (1978) as reporting the optimum water temperature range for fry and juvenile rearing appearing to be 55°F to 60°F. In addition, Rich (1987) reported the temperature stress zones for each life stage of steelhead in the lower American River (Table 2, Page 21). For fry and juvenile rearing, the low temperature stress zone was reported to be 60.1°F to 68°F (15.6°C to 20°C). The medium temperature stress zone was reported to be 68.1°F to 72.5°F (20.06°C to 22.5°C). The high temperature stress zone was reported to be above 72.5°F (22.5°C) (Rich 1987).

Cech et al. (1999) performed a series of studies using Nimbus strain steelhead from the Nimbus State Fish Hatchery to determine the thermal preference and bioenergetics of age-0 winter-run steelhead. The authors concluded that the preferred water temperature for Nimbus steelhead is 62.6°F to 68°F (17°C to 20°C). In addition, they observed that steelhead reared within the “preferred” water temperature range (66.2°F/ 19°C) exhibited higher growth rates than those reared under different thermal regimes. Critical thermal maxima for the steelhead used in these studies increased with increasing acclimation temperature and ranged from 81.5 ± 0.31°F (27.5 ± 0.17°C) for 51.8°F (11°C) acclimated fish to 85.82 ± 0.45°F (29.9 ± 0.25°C) for 66.2°F (19°C) acclimated fish (Cech et al. 1999).

In two sets of studies performed by Castleberry et al. (1993), the authors reported that 68°F (20°C) approaches the optimal temperature for swimming performance of steelhead captured in the American River. However, the authors suggest that water temperature plays a less important role than other variables in other physiological processes including RNA/DNA ratios, lipid content, gill ATPase activity, and growth rates.

Because many of the reported results were obtained from experiments performed under laboratory conditions, care should be taken not to overestimate the value of the data collected (Sullivan et al. 2000). Effects due to variables that exist in natural environments such as the presence and density of predators, solar input, variation in food availability, and the stochastic events that could occur, such as unusually heavy rains, are minimized in laboratory studies (Castleberry et al. 1993).

Observations of rearing juvenile steelhead in the Santa Ynez River and its tributaries in Santa Barbara County suggest that steelhead tolerate water temperatures above those generally considered within the thermal preference range for the species. During the summer of 1995, young-of-year steelhead were observed to be generally healthy and actively feeding in water that was 78.4°F (25.8°C) (pers. com., C. H. Hanson, Hanson Environmental, 2003). In addition, steelhead were able to survive over the summer in stream reaches where average daily water temperatures ranged from 68°F to 73.4°F (20°C to 23°C) and where daily maximum surface water temperatures as high as 78.8°F (26°C) were observed (pers. com., C. H. Hanson, Hanson Environmental, 2003). It is possible, however, that cold water refugia existed within the stream reaches where juvenile steelhead were observed.

Nielsen and others reported observing juvenile steelhead in the Eel River feeding in water with surface water temperatures up to 75.2°F (24°C) (Nielsen et al. 1994). The study also documented, however, that steelhead utilized thermally stratified pools in the Eel River. Therefore, the observed juveniles may have entered the relatively warm surface water for short periods to feed.

Surveys performed on in the Russian River by the Sonoma County Water Agency showed a significant correlation between juvenile steelhead distribution and water temperature. Surveyed reaches that had the highest maximum daily water temperatures also had the fewest number of observed steelhead. However, reaches in which juvenile steelhead were observed had water temperatures that were above the generally reported preferred water temperatures (Table 5.3-1). According to the Sonoma County Water Agency (Cook 2003), juvenile steelhead observed in reaches where maximum water temperatures reached 71.6°F and 72.5°F (22°C and 22.5°C) appeared “...*healthy and vigorous, not stressed or lethargic from high water temperatures.*” Those reaches contained approximately 265 steelhead/km and 37 steelhead/km respectively. Reaches where maximum water temperatures reached 77°F and 75.2°F (25°C and 24°C) contained <1 and 7 steelhead/km respectively (Cook 2003).

5.3 WATER TEMPERATURE LIMITS

Literature describing the thermal preferences and tolerances of steelhead from regions outside California was relatively abundant compared to literature describing thermal preferences and tolerances of California strains. All sources were utilized to identify water temperature limits. A wide range of preferred and optimal water temperatures have been reported for juvenile steelhead rearing, as well as for steelhead without reference to any specific lifestage. Table 5.3-1 shows the reported preferred, optimum, critical thermal maximum (CTM), and upper incipient lethal water temperatures (UILT) for steelhead reported by various authors. Included in the table are LT10 values reported by some authors. The CTM is the arithmetic mean of the water temperatures required to produce loss of equilibrium (LE) or death (DT) in a series of trials. The LT10 values are the water temperatures at which 10% of the population suffers mortality. UILT, sometimes referred to as LT50, is the water temperature at which 50% of the population suffers mortality (McCullough 1999).

Table 5.3-1. Preferred, Optimum, Critical Thermal Maximum, and Upper Incipient Lethal Water Temperatures for Steelhead.

Species	Source	Origin	Preferred	Optimum	CTM	LT10	UILT (LT50)
Steelhead (juvenile)	Myrick and Cech 1999	Feather River Fish Hatchery	62.6°F – 68°F	*	83.12°F – 85.82°F	*	*
Steelhead (juvenile)	Cech and Myrick 1999	Nimbus State Fish Hatchery	62.6°F – 68°F	*	81.5°F – 85.82°F	*	*
Rainbow trout (juvenile)	Hokanson et al. 1977	Lake Superior	*	62.96°F - 65.48°F constant treatment 59.9°F – 63.14°F fluctuating treatment	*	*	78.08°F (acclimated at 60.8°F)
Rainbow trout (juvenile)	Cherry et al. 1975	Virginia	59°F – 64°F	*	*	*	*
Steelhead (no age given)	Bell 1973, 1986, 1991 (cited by Bjornn and Reiser 1991, Reiser and Bjornn 1979, McEwan and Jackson 1996, Barnhart 1986)	Unknown	45°F – 58°F	50°F 55°F-	75°F	*	*
Steelhead (fry)	DWR and USBR 2000 (cites McEwan and Jackson 1996)	Unknown	45°F – 60°F	*	*	*	*

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Species	Source	Origin	Preferred	Optimum	CTM	LT10	UILT (LT50)
Steelhead	Sullivan et al. 2000	Unknown	*	*	*	80.6° F at 1 hour 84.4 at 0.1 hour	See Table 5.3-3 Below
Rainbow trout (juvenile)	Threader and Houston 1983 <i>in</i> McCullough 1999	Ontario	*	*	*	*	76.8°F acclimat ed at 53.6°F 77.72°F acclimat ed at 60.8°F 78.62 ° acclimat ed at 68°F
Steelhead (juvenile)	Grabowski 1973 <i>in</i> McCullough 1999	Dworshak National Fish Hatchery, Idaho	*	59°F	*	*	*
Rainbow trout (unknown)	Charlon et al. 1970 <i>in</i> McCullough 1999	France	*	*	*	*	79.52°F acclimat ed at 75.2°F
Rainbow trout (unknown)	Bidgood and Berst 1969 <i>in</i> McCullough 1999	Great Lakes	*	*	*	*	77°F - 78.8°F acclimat ed at 59°F
Rainbow trout (unknown)	Cherry et al. 1977 <i>in</i> McCullough 1999	Great Lakes	*	*	*	*	77°F acclimat ed 75.2°F
Rainbow trout (unknown)	Stauffer et al. 1984 <i>in</i> McCullough 1999	Great Lakes	*	*	*	*	78.8°F acclimat ed at 75.2°F
Rainbow trout (unknown)	Alabaster 1964 <i>in</i> McCullough 1999	Ontario	*	*	*	*	80.06°F acclimat ed at 68°F
Rainbow trout (unknown)	Black 1953 <i>in</i> McCullough 1999	Summerland Hatchery British Columbia	*	*	*	*	75.2°F acclimat ed at 51.8°F

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Species	Source	Origin	Preferred	Optimum	CTM	LT10	UILT (LT50)
Rainbow trout (unknown)	Kaya 1978 <i>in</i> McCullough 1999	Ennis Hatchery, Montana Winthrop Hatchery, Washington	*	*	*	*	79.16°F acclimated at 76.1°F 79.16°F acclimated at 76.1°F
Rainbow trout (2-3 months)	Grande and Anderson 1991 <i>in</i> McCullough 1999	Unknown	*	*	79.34°F acclimated at 62.6°F	*	*
Rainbow trout (unknown)	Lee and Rinne 1980 <i>in</i> McCullough 1999	Williams Creek Hatchery, Arizona	*	*	84.83°F when acclimated at 68°F 83.3°F when acclimated at 50°F (Both studies CTM determined to LE)	*	*
Steelhead (unknown)	Wurtsbaugh and Davis 1977 <i>in</i> McCullough 1999	Oregon Coastal Stream	*	Less than 61.7°F	*	*	*
Steelhead (fry and juvenile)	Rich 1987 (cites Bovee 1978)	Unknown	*	55°F – 60°F	*	*	*
Steelhead (juvenile)	Reiser and Bjornn 1979	Unknown	*	45.1°F – 58.3°F	*	*	*

Moyle (2002) reports that the optimal water temperatures for growth of rainbow trout are around 59°F to 64.4°F (15°C -18°C), a range that corresponds to water temperatures selected in the field where possible. Hokanson and others (1977) reported that the optimum water temperature for growth in rainbow trout from Lake Superior stock is 63°F to 65.5°F (17.2°C to 18.6°C) when exposed to a constant temperature. When exposed to fluctuating water temperatures, such as those experienced during the diel cycle in a natural environment, the optimal reported water temperature range for growth is 59.9°F to 63.14°F (15.5°C to 17.3°C). In addition, the upper incipient lethal temperature for juvenile rainbow trout acclimated at 60.8°F (16°C) was reported to be 78.08°F (25.6°C) (Hokanson et al. 1977). Others have cited the studies of Hokanson et al. (1977) when discussing suitable water temperature ranges for juvenile rainbow trout growth (Evans 1990; McCullough 1999). To illustrate how water temperatures could affect the growth of populations, Hokanson and others (1977) reported that the maximum water temperatures at which a rainbow trout population could maintain its initial weight for 40 days was 73.4°F (23°C) for a constant water temperature, or 69.8 ± 6.84°F (21 ± 3.8°C) for a fluctuating water temperature regime (Hokanson et al. 1977). Cherry and others

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(1975) reported that the level of thermal acclimation had a direct effect on the range of water temperatures selected by rainbow trout. For example, the reportedly preferred water temperature for fish acclimated at 59°F (15°C) was 62.4°F (16.9°C), while those acclimated at 64.4°F (18°C) selected a water temperature of 64.6°F (18.1°C). The authors concluded that, when acclimated at water temperatures between 59°F and 64.4°F, rainbow trout selected preferred water temperatures that were approximately equal to their acclimation water temperatures, which represented their final water temperature preferenda (Cherry et al. 1975). Table 5.3-2 shows the results of the studies performed by Cherry et al. (1975) on acclimation and preferred water temperatures for rainbow trout.

Table 5.3-2: Preferred Water Temperature Of Rainbow Trout (°C).

Rainbow trout							
Acclimation Temperature	6	9	12	15	18	21	24
Preferred Temperature	11.6	12.6	14.4	16.9	18.1	20.1	22.0

Modified from Cherry et al. 1975

Bell produced three works that are often cited when describing suitable water temperatures for salmonids. Two of the three works report that the preferred water temperature range for steelhead is 45°F to 58°F (7.2°C to 14.4°C) (Bell 1986; Bell 1991). In addition, Bell (1986 and 1991) reports that the optimum water temperature range is 50°F to 55°F (10°C to 13°C), and that the upper lethal limit is 75°F (23.9°C). Barnhart (1986) provides water temperature ranges similar to Bell. He reported that, for young steelhead, the preferred water temperature is 45°F to 58.1°F (7.2°C to 14.5°C), the reported optimal water temperature is 50°F (10°C), and reported upper lethal temperature is 75°F (23.9°C) (Barnhart 1986). However, Barnhart cited the 1973 version of Bell's Fisheries Handbook of Engineering Requirements and Biological Criteria as the source for his reported water temperature preferenda, optima, and maxima (Barnhart 1986). Bjornn and Reiser (1991) have also cited Bell (1986) when reporting preferred and upper lethal water temperatures for steelhead (Table 4.8 in Bjornn et al. 1991).

Bovee (1978) provides probability of use curves for the family salmonidae. For fry and juvenile winter steelhead, analysis of the curves shows that the 50% probability of use occurs in the water temperature range between 52°F and 66°F (11.1°C and 18.9°C) for fry, and 48°F and 66°F (8.9°C and 18.9°C) for juveniles. The 80% probability of use occurs within the range of 52°F and 65°F (11.1°C and 18.3°C) (Bovee 1978).

Sullivan et al. (2000) utilized data from Brett (1952) to develop LT10 curves for several salmonid species. LT10 represents the water temperature at which 10% mortality of an experimental population occurs. Sullivan and others reported that the LT10 for steelhead occurs at 80.6°F (27°C) at one hour and at 84.4°F (29.1°C) at 0.1 hour (Brett 1952; Sullivan et al. 2000). Table 5.3-3 shows the reported water temperatures that would cause mortality of 10% of the population calculated from relationships provided by various authors.

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Table 5.3-3: Reported LT10 For Yearling Rainbow Trout (°C).

Acclimation Temperature	One hour LT10	Six hour LT10
15	27.2	25.7
18	27.5	26.9
20	28.0	26.8
20	28.2	26.5
20	28.5	26.8
20	28.0	26.3
20	28.3	26.3
<i>From Sullivan et al. 2000</i>		

McCullough (1999) performed an extensive literature review regarding the effects of alterations to the water temperature regime on freshwater lifestages of salmonids. Information on reported water temperature preferences, optima, and maxima synthesized from various authors is shown in Table 5.3-1. The following are studies reported in McCullough (1999). Threader and Houston (1983) performed 24-hour LT50 experiments on juvenile rainbow trout acclimated at 53.6°F (12°C), 60.8°F (16°C) and 68°F (20°C). According to McCullough, the experiments revealed that LT50 for juvenile rainbow trout was similar regardless of acclimation temperature. The reported LT50 for each group was 76.8°F (24.6°C), 77.72°F (25.4°C), and 78.62°F (25.9°C) respectively (McCullough 1999). Grabowski (1973) reported that of three water temperature treatments, 46.4°F (8°C), 59°F (15°C), and 64.4°F (18°C) to which steelhead juveniles were exposed, steelhead growth rates were highest at 59°F (15°C). Fish in the study originated from the Dworshak National Fish Hatchery in Idaho (McCullough 1999). Lee and Rinne (1980) reported that the critical thermal maxima to loss of equilibrium for rainbow trout acclimated at 50°F (10°C) and 68°F (20°C) were 83.3°F (28.5°C) and 84.83°F (29.35°C) respectively (McCullough 1999). Grande and Anderson (1991) reported that for two to three month old rainbow trout acclimated at 62.6°F (17°C), the critical thermal maximum was 79.34°F (26.3°C). No mention was made of the origin of the fish in Grande and Anderson's (1991) study (McCullough 1999). Wurtsbaugh and Davis (1977) found that for juvenile steelhead captured from an Oregon coastal stream, that water temperatures less than 61.7°F (16.5°C) were optimal for growth (McCullough 1999).

5.4 EFFECTS OF INCREASED WATER TEMPERATURES

The effects of increased water temperatures on rearing salmonids have been reported to range from behavioral modifications and physical and physiological changes, to death (Bjornn et al. 1991; Brett 1952; Crawshaw 1977; Evans 1990; Hokanson et al. 1977; Hughes et al. 1978; McCullough 1999; Rich 1987; Sullivan et al. 2000; Winfree et al. 1998). The type and severity of the effects of elevated water temperatures on salmonids have been reported to be related to the magnitude and duration of elevated water temperature exposure (Sullivan et al. 2000). Winfree et al. (1998) reported that steelhead raised from first-stage feeding fry for 22 weeks in elevated water temperatures of 59°F (15°C) compared to fish raised at low temperatures 50°F (10°C)

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showed increased dorsal fin erosion. Dorsal fin index differed by up to 65% between treatments (Winfree et al. 1998). However, it was evident that fish in high density treatments showed increased dorsal fin erosion compared to fish raised at the same water temperature in lower densities and, therefore, water temperature may play only a small role in dorsal fin erosion.

Wedemeyer (1973) reported that elevated water temperatures caused a variety of physiological changes in juvenile steelhead including hyperglycemia, hypocholesterolemia, increased blood hemoglobin levels, and decreased regulatory precision of blood sugar (McCullough 1999). Evans (1990) reported that rainbow trout (130-250g) had a 53% reduction in standard metabolic rate during warm acclimation. Additionally, Evans (1990) reported that acute water temperature decreases caused a 74% reduction in standard metabolic rate compared to fully acclimated fish. Conversely, cold acclimated fish exposed to a water temperature of 68°F (20°C) were reported to show a 112% increase in standard metabolic rate compared to fish acclimated at 68°F (Evans 1990). Clearly, acute and gradual water temperature changes change metabolic rates and, thus, would be expected to affect steelhead survival during rearing. Crawshaw (1977) hypothesized that changes in metabolism, caused by increased oxygen consumption at elevated water temperatures, could potentially interfere with acid-base balance and enzyme-substrate relationships. Indeed, Crawshaw (1977) reported that oxygen consumption in rainbow trout increased with an increase in water temperature from 50.9°F to 68°F (10.5°C to 20°C) (Crawshaw 1977). Hughes et al (1978) reported that increased water temperatures of between 5.4°F and 7.2°F (3°C - 4°C) and 12.6°F and 14.4°F (7°C – 8°C) above ambient stream water in an Oregon coastal stream increased metabolic rates in juvenile steelhead (Hughes et al. 1978). Cech and Myrick (1999), however, reported that juvenile Nimbus Strain steelhead oxygen consumption was independent of temperature (Cech et al. 1999). In addition, Cech and Myrick (1999) determined that food conversion efficiency in Nimbus Strain steelhead was unaffected by thermal regime. Threader and Houston (1983) reported that food conversion efficiency in juvenile rainbow trout decreased as water temperatures increased from 61.2°F to 72.5°F (16.2°C to 22.5°C) (McCullough 1999). Growth rates in Nimbus Strain steelhead, however, had an increasing trend up to 66.2°F (19°C) (Cech et al. 1999). Feather River steelhead, examined by the same authors, however, showed growth rates independent of water temperature (Myrick et al. 1999). It also has been reported that the swimming performance of rainbow trout, as well as other salmonids, decreased with increased water temperature. However, it was reported that performance only decreased above certain threshold water temperatures (68°F or 20°C) for rainbow trout. The threshold was reportedly lower for other salmonids (Bjornn et al. 1991).

Behavioral changes related to elevated water temperatures also have been reported. Bjornn and Reiser (1986) and Bermann and Quinn (1991) reported that salmonids change their behavior and lateral stream position in order to help thermoregulate (Berman et al. 1991; Bjornn et al. 1991).

In addition to physical, physiological, and behavioral changes associated with elevated water temperatures, decreased resistance to disease outbreaks and increased predation rates also have been reported (McCullough 1999; Sullivan et al. 2000).

Mortality rates have also been reported to increase in juvenile rainbow trout reared in water temperatures that fluctuate between 65.12°F and 78.8°F (18.4°C and 26°C).

6.0 CONCLUSIONS

Statistical analysis to determine the significance of the differences between thermal tolerances for steelhead in different regions was not performed due to the differences in experimental protocols and metrics reported among studies. For example, Myrick and Cech (1999) reported preferred water temperature ranges for Feather River juvenile steelhead while others report optimal water temperatures. Some authors, such as Bell (1986, 1991) do not provide an indication of where the experimental fish were collected or the ages of experimental fish. In addition, acclimation water temperatures were different between the studies performed by Cherry (1975) and Myrick and Cech (1999). Therefore, because reported metrics differ between authors, meaningful statistical analyses are difficult. Without these types of analyses, however, it is also difficult to determine whether Feather River steelhead exhibit significantly different thermal preferences and tolerances to other steelhead strains. Observations of thermal preferences reported in the literature, despite obvious differences in study design, do indicate that Feather River and Nimbus Strain steelhead preferentially choose higher water temperatures than those reported for steelhead from regions outside the Central Valley of California. In addition, statistical analyses performed by the authors showed that no significant relationship between growth rate and thermal regime for Feather River steelhead exists. An interesting result that emerged from the Myrick and Cech (1999) study was that the critical thermal maxima displayed by wild steelhead were significantly higher than their hatchery counterparts. However, the preferred water temperature range was not significantly different between fish of wild or hatchery origin (Myrick et al. 1999).

Average monthly water temperatures in the reach of the Feather River from the Fish Barrier Dam to the Thermalito Afterbay outlet range from 47°F (8.3°C) in winter to 65°F (18.3°C) in the summer. Water temperatures downstream of the Thermalito Afterbay outlet are generally warmer, with the maximum mean daily water temperature at the Thermalito Afterbay outlet reaching approximately 70°F (21.1°C) in the summer (DWR 2001).

Naturally spawned Feather River steelhead have been observed to rear successfully at water temperatures near 65°F (18.3°C) (DWR et al. 2000). In addition, young-of-year Feather River steelhead have also been observed rearing in habitats where average daily water temperatures were 63°F (17.2°C), and where daily maximal water temperature exceeded 66°F (18.9°C) (DWR et al. 2000).

Because Myrick and Cech (1999) and Myrick (1998) performed the only available studies on thermal preferences of Feather River steelhead, their results were used to determine the suitability of Feather River water temperatures for rearing juvenile steelhead. They reported the thermal preference of juvenile Feather River steelhead to be between 62.6°F to 68°F (17°C to 20°C). In addition, apparently healthy juvenile steelhead have been observed rearing in other rivers in California with daily maximum water temperatures as high as 72.5°F (pers. com., C. H. Hanson, Hanson Environmental, 2003). Because the average monthly water temperatures between the

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Fish Barrier Dam and Thermalito Afterbay Outlet do not exceed 65°F, it is unlikely that adverse physical or physiological effects would occur to rearing Feather River juvenile steelhead in the reach between the Fish Barrier Dam and the Thermalito Afterbay Outlet. In addition, behavioral thermoregulation could attenuate localized, increased water temperatures should they occur. Because snorkel surveys on the Feather River indicate that little to no steelhead rearing occurs below the Thermalito Afterbay Outlet (DWR et al. 2000), it is unlikely that high water temperatures that occur below the outlet would have significant adverse effects on steelhead rearing in the Feather River.

Enclosure experiments are scheduled to be performed by DWR to determine growth rates and food availability for rearing juvenile steelhead within the Feather River between the Fish Barrier Dam and the Thermalito Afterbay Outlet. Once completed, correlations could then be made to determine whether water temperatures in the Feather River affect rearing juvenile steelhead or their food base.

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